USGS Final Technical Report

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Title:	**Toward Zonation of Earthquake Source Properties in Southern California**

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Abstract

The goal of the proposal was to test if earthquake source properties are statistically similar everywhere, as is usually assumed, or whether there are systematic regional differences that may be used to develop "zonation" of earthquake sources. Toward this goal we developed and applied techniques to detect signatures of damage-related-radiation that can modify the amount, frequency content and tensorial composition of radiation to the bulk, and directivity of earthquake ruptures on given fault sections that can affect the azimuthal distribution of seismic ground motion. The former is expected in complex fault regions where earthquake ruptures break fresh rocks, while the latter is expected in highly localized fault zones with bimaterial interfaces that separate different rock bodies. The studies have focused on the following four research directions: (1) Development of a computational tool for analysis of full source tensor properties including isotropic and CLVD components with the gCAP method and 3D velocity model. (2) Estimating and analyzing the scalar potency and moment of >11,000 earthquakes around the San Jacinto fault zone. (3) Development and application of an automated procedure for estimating directivity and other earthquake source properties from body wave spectra in southern California. (4) We also utilized a unique data set recorded within and around the rupture zone of the 1999 Izmit earthquake to analyze ratios of corner frequencies of P and S waves as potential signatures of damage-related-radiation. Below we provide additional details on the main results associated with each research direction. Continuing studies using the developed techniques to perform systematic analysis of source properties in southern California will clarify the extent of zonation of earthquake sources, and provide important information for earthquake source physics and refined estimates of seismic shaking hazard.

Research Results

(1) Full source tensors of San Jacinto fault zone earthquakes based on the gCAP inversion method and 3D velocity model (*Ross et al., 2015*)

We analyze full source tensor properties of moderate-sized earthquakes in the complex trifurcation area of the San Jacinto Fault Zone (SJFZ), CA, with a focus on isotropic radiation that may be produced by rock damage in the source volumes. The earthquake mechanisms are derived with generalized 'Cut and Paste' (gCAP) inversions of 3-component waveforms typically recorded by >70 stations at regional distances. The gCAP method includes parameters ζ and χ representing, respectively, the relative strength of the isotropic and CLVD source terms. In a previous analysis using the 1D velocity model of Hadley and Kanamori (1977) we found statistically significant explosive isotropic components for at least six of seven examined events, corresponding to ~0.4-8% of the total potency/moment of the sources. Possible errors due to station variability and inaccurate Green's functions were quantified with bootstrap resampling and velocity model perturbations. Here we expand the gCAP inversions to incorporate a 3D velocity model combining the regional SCEC community model and the detailed tomographic results of Allam and Ben-Zion (2012) and Zigone et al. (2015) for the region around the SJFZ. The 3D Green functions are calculated with the finite difference algorithm of Graves (1996). We tested the accuracy of the computational method by comparing finite difference and FK calculations for the 1D Hadley and Kanamori (1977) model. Next, the employed 3D velocity model was used to calculate the eighteen relevant 3D Green's functions. Results based on the 3D Green's functions for moderate SJFZ earthquakes will be presented in the meeting.

(2) Analysis of earthquake body wave spectra for potency and magnitude values: Implications for magnitude scaling relations (*Ross et al., 2016*)

We develop a simple methodology for reliable automated estimation of the low-frequency asymptote in seismic body wave spectra of small to moderate local earthquakes. The procedure corrects individual P- and S-wave spectra for propagation and site effects and estimates the seismic potency from a stacked spectrum. The method is applied to >11,000 earthquakes with local magnitudes $0 < M_L < 4$ that occurred in the Southern California plate-boundary region around the San Jacinto fault zone during 2013. Moment magnitude M_w values, derived from the spectra and the scaling relation of Hanks & Kanamori (1979), follow a Gutenberg-Richter distribution with a larger *b*-value (1.22) from that associated with the M_L values (0.93) for the same earthquakes. The completeness magnitude for the M_w values is 1.6 while for M_L it is 1.0. The quantity ($M_w - M_L$) linearly increases in the analyzed magnitude range as M_L decreases. An average earthquake with $M_L = 0$ in the study area has an M_w of about 0.9. The developed methodology and results have important implications for earthquake source studies and statistical seismology.

(3) Towards reliable automated estimates of earthquake source properties from body wave spectra *(Ross and Ben-Zion, 2016)*

We develop a two-stage methodology for automated estimation of earthquake source properties from body wave spectra. An automated picking algorithm is used to window and calculate spectra for both P and S phases. Empirical Green's functions are stacked to minimize non-generic source effects such as directivity, and are used to deconvolve the spectra of target earthquakes for analysis. In the first stage, window lengths and frequency ranges are defined automatically from the event magnitude and used to get preliminary estimates of the P and S corner frequencies of the target event. In the second stage, the preliminary corner frequencies are used to update various parameters to increase the amount of data and overall quality of the deconvolved spectral ratios (target event over stacked Empirical Green's function). The obtained spectral ratios are used to estimate the corner frequencies, strain/stress drops, radiated seismic energy, apparent stress, and the extent of directivity for both P- and S-waves. The technique is applied to data generated by five small to moderate earthquakes in southern California at hundreds of stations. Four of the five earthquakes are found to have significant directivity. The developed automated procedure is suitable for systematic processing of large seismic waveform data sets with no user involvement.

(4) Corner frequency ratios of *P* and *S* waves and strain drops of earthquakes recorded by a tight network around the Karadere segment of the North Anatolian Fault Zone: Evidence for non-classical source processes *(Yang and Ben-Zion, 2016)*

We present a method for estimating ratios of P and S waves corner frequencies (R_{cf}) and earthquake strain drops by joint analysis of P and S source spectra of neighboring groups of events. The method is applied systematically to data generated by ~9000 earthquakes around the Karadere segment of the North Anatolian Fault Zone. The results indicate several regions that produce consistently R_{cf} values higher (e.g. > 2) than expected from classical earthquake source models. These are associated generally with fault sections having strong geometrical heterogeneities, shallow depth sections and/or locations without large pre-existing surface trace. Earthquake ruptures in such regions are likely to generate significant rock damage and tensile components of faulting. To assess whether the observed high R_{cf} values are produced by enriched high frequency P waves, reduced high frequency S waves or both, we compare the associated P and S spectra with mean/median results. The analysis suggests that the high R_{cf} values of shallow events (depth < 4 km) are generated primarily by reduced high frequency S radiation, and that the contribution from elevated high frequency P radiation increases with depth and proximity to geometrical complexities. The results highlight the importance of considering carefully the existence of some volumetric source components in earthquake rupture processes.

Publications Supported by this Grant

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Yang, W. and Y. Ben-Zion, 2016. Corner frequency ratios of *P* and *S* waves and strain drops of earthquakes recorded by a tight network around the Karadere segment of the North Anatolian Fault Zone: Evidence for non-classical source processes, *Geophys. J. Int*., 205, 220–235, doi: 10.1093/gji/ggv560.